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Working Paper

High technology governance and institutional adaptiveness: do technology policies usefully promote commercial innovation within the German biotechnology industry?

Discussion paper // Wissenschaftszentrum Berlin für Sozialforschung, Forschungsschwerpunkt Arbeitsmarkt und Beschäftigung, Abteilung Wirtschaftswandel und Beschäftigung, No. FS I 99-307

Provided in cooperation with:
Wissenschaftszentrum Berlin für Sozialforschung (WZB)

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für Sozialforschung

discussion paper

FS I 99 - 307

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June 1999
ISSN Nr. 1011-9523

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For helpful criticism I'd like to thank Karen Adelberger, Susanne Giesecke, Jerald Hage, Hannah Kettler, J. Rogers Hollingsworth, Ernst Homburg, Marius Meeus, Bart Noteboom, David Soskice, Birgitte Unger, Frans van Waarden, and Richard Whitley. For institutional support I am grateful to Netherlands Institute for Advanced Studies. Financial support for field research was provided by the German Ministry for Education and Research (BMBF).

ZITIERWEISE/CITATION

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Discussion Paper FS I 99 -307
Wissenschaftszentrum Berlin für Sozialforschung 1999

Forschungsschwerpunkt: Arbeitsmarkt und Beschäftigung	**Research Area:** Labour Market and Employment
Abteilung: Wirtschaftswandel und Beschäftigung	**Research Unit:** Economic Change and Employment

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Abstract

The German economy has widely been seen as failing to develop commercial innovation competencies necessary to compete in biotechnology, information technology, and other emerging new industries. Starting in the mid-1990s the German government has instituted a series of new technology policies designed to orchestrate the development of small entrepreneurial technology firms. These policies have fostered several hundred new entrepreneurial start-ups in Germany, many of which have adopted strategies that differ dramatically from those commonly associated with small and medium sized German firms. Developments in Germany represent an interesting challenge to prevailing institutional theory as applied to the study of advanced industrial economies, which tends to view the characteristics of organizations as strongly constrained by the orientation of a number of key national institutional frameworks. Focusing on biotechnology, this article examines the relative importance of national institutional frameworks as opposed to sector-specific policies that are presently pervasive in Germany. Analysis of the new firms demonstrates that Germany's new technology policies have facilitated important extensions within the business system that have, for the first time, allowed the systematic promotion of entrepreneurial technology companies. However, the dominant strategies of market specialization and company organizational patterns found within these companies have been strongly influenced by incentives and constraints created by long-established national institutional structures.

Zusammenfassung

Bis vor kurzem war es vorherrschende Meinung, daß die deutsche Volkswirtschaft es versäumt hatte, marktorientierte Innovationskompetenzen zu entwickeln, um in Biotechnologie, Informationstechnologie und anderen neuen Hochtechnologiebranchen erfolgreich am Wettbewerb teilnehmen zu können. Seit Mitte der neunziger Jahre verfolgt die Bundesregierung eine neue Technologiepolitik mit dem Ziel, die Entwicklung kleiner Hochtechnologieunternehmen zu initiieren und zu unterstützen. Dies führte bisher zu mehreren hundert Neugründungen. Die Unternehmensstrategien vieler dieser Unternehmen weichen sehr stark von jenen Handlungsmustern ab, die normalerweise mit den kleinen und mittelständischen deutschen Unternehmen assoziiert werden.

Diese Entwicklungen in Deutschland stellen eine interessante Herausforderung an die vorherrschende Institutionentheorie dar, wie sie zur Analyse hochentwickelter Volkswirtschaften verwendet wird. Danach werden die spezifischen Merkmale von Unternehmen weitgehend als Folge prägender nationaler institutioneller Rahmenbedingungen verstanden.

In der vorliegenden Studie der Biotechnologie-Branche wird der relative Einfluß nationaler Institutionengefüge als ein gegensätzlicher Ansatz zu den in Deutschland noch vorherrschenden sektorspezifischen Politiken untersucht. Die Analyse der neugegründeten Unternehmen zeigt, daß diese neue Technologiepolitik den Weg zu erweiterten Möglichkeiten im ökonomischen Handeln geebnet und damit zum ersten Mal die systematische Förderung von Hochtechnologie-Unternehmen ermöglicht hat. Trotzdem: Die vorherrschenden Strategien der Spezialisierung auf definierte Märkte und die Organisationsmuster der untersuchten Unternehmen werden nach wie vor von den Anreizen und Einschränkungen des lange bestehenden nationalen Institutionengefüges stark geprägt.

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1. Introduction

Through the 1980s and early 1990s the German economy has widely been seen as failing to develop commercial innovation competencies necessary to compete in biotechnology, information technology, and other emerging new industries (Soskice, 1997; Streeck, 1996; Casper and Vitols, 1997). Poor competitive performance in these high-tech sectors is indicative of a broader failure of the German economy to develop clusters of entrepreneurial science-based firms that have been a major catalyst of technological development in the United States. Starting in the mid-1990s the German government has instituted a series of new technology policies designed to orchestrate the development of small entrepreneurial firms. These policies have fostered several hundred new entrepreneurial start-ups in Germany, many of which have adopted strategies that differ dramatically from those commonly associated with small and medium sized German firms. Developments in Germany represent an interesting challenge to prevailing institutional theory as applied to the study of advanced industrial economies, which tends to view the characteristics of organizations as strongly constrained by the orientation of a number of key national institutional frameworks. Focusing on biotechnology, this article examines the relative importance of national institutional frameworks as opposed to sector-specific policies that are presently pervasive in Germany. Through doing so, it attempts to create an analytic framework with which to appraise patterns of institutional adaptation within the economy.

The recent renaissance in the fortunes of German high-technology industry, and in particular the strong role of government technology policies in the creation of these new firms, has given empirical support for a new perspective on the role of institutions in the governance of the economy, what I call the „resource orchestration“ approach. It suggests that government policies can create customized institutional frameworks to support particular sectors. To foster new technology firms, the German government has crafted new technology transfer programs, built science parks, dispersed financial subsidies and research and development grants for start-up firms, and sponsored a series of minor financial reforms to introduce American-style capital markets for technology firms in Germany. This view strongly opposes a long line of research generally supporting a „varieties of capitalism“ theoretical perspective, which suggests that differences in national institutional architectures are responsible for stark patterns of industrial specialization across the advanced industrial economies. Within this framework, it has been repeatedly argued that German institutional frameworks create obstacles to the construction of entrepreneurial technology firms engaging in radical innovation activities, but advantage the organization of competencies needed for a variety of industries that rely on continuous process innovations within sophisticated, but established technologies.

Through comparison with the United States, this article examines how national institutional frameworks are combining with resources and incentives created by Germany's new technology policies to encourage particular strategies of commercial innovation by entrepreneurial biotechnology firms. To do so, I examine different segments of the bio-medical related biotechnology industry, and in particular contrast a number of key technological characteristics and related organizational dilemmas pervasive within two such segments, therapeutics and platform technologies. Industry specialization data reveal that German firms have overwhelmingly chosen to specialize in the platform technology segment of biotechnology, while firms in the United States, though also present in the platform technology field, tend to dominate the therapeutics segment.

Explaining this divergent pattern of specialization is the primary empirical puzzle of the paper. While firms in each of these segments are „entrepreneurial" in the sense that most firms are small, technology oriented, and have rapid growth potential, important differences exist in a number of organizational dilemmas faced by firms. I examine differences in the broad technological regime underpinning therapeutics and platform technology segments of biotechnology in order to assess different organizational dilemmas posed by the two segments. These include differences in the financial risks, employee motivational problems, and the orchestration of adequate human resources. I then assess how sector specific technology policies interact with national institutional frameworks to influence the ability of firms to solve these organizational dilemmas.

To establish these points, the article is structured around three empirical sections followed by a conclusion. First, to frame the debate and introduce key concepts, I discuss competing institutional perspectives on the sources of organizational structures within technologically innovative commercial environments.

Second, I analyze technological regime characteristics and related organizational dilemmas of the therapeutics and platform technology segments of biotechnology. Through comparison with the United States, the final empirical section examines how German institutional structures influence the orchestration of commercial innovation within both industry segments, and in particular how key organizational dilemmas are resolved. The paper concludes with a discussion on the sources of institutional adaptiveness within the German economy and the implications of this research for comparative institutional theory of the firm and its environment.

2. Institutions and national patterns of innovation: two perspectives

a) The „varieties of capitalism“ perspective

Institutional scholars within the comparative political economy and organizational studies fields have examined variations in economy-wide national institutional frameworks and suggested how particular institutional configurations advantage the construction of different organizational patterns within the economy. Crouch and Streeck, 1997; Hollingsworth and Boyer, 1997; Whitley 1999; Soskice 1994). Because Germany and the United States have been identified as advanced industrial countries with widely dissimilar national institutional framework configurations, much theoretical analysis has centered on US-German comparisons (see Soskice, 1997).

Germany may be characterized as a „coordinated market economy“ (Soskice, 1994) underpinned by a regulatory private law system. The law is regulative in the sense that it designates statutory bargaining rights to unions, employers, and other social actors within the business system, while granting courts extensive powers to police the distribution of risks within contracts. Non-market forms of business coordination are facilitated by the embeddedness of large firms within networks of powerful trade and industry associations, as well as a similar, often legally mandated, organization of labor and other interest organizations within para-public institutions (Katzenstein, 1987, 1989). Businesses engage these associations to solve a variety of incomplete contracting dilemmas and create important non-market collective goods. To discourage individual companies from exiting the collective business system, German public policy relies on the legal system to regulate a wide variety of inter-firm and labor contracts as well as sustain neo-corporatist bargaining environments through the delegation of issue-area specific bargaining rights to unions and other stake-holders within firms (Keller, 1991).

By contrast, the United States is characterized by a liberal market economy. Business coordination depends primarily on market oriented transactions and the use of a flexible, enabling private legal system to facilitate a variety of complex contracting situations. Because courts refuse to adjudicate incomplete contracts (see Schwarz, 1992), market participants need to specify control rights in contract to as full an extent as possible or, when this is not possible, use extremely high-powered performance incentives to align interests within and across organizations (Easterbrook and Fischel, 1991; more generally Milgrom and Roberts 1992). Table 1 outlines the main institutional differences across the two countries.

These contrasting patterns of market regulation and business coordination have lead to substantial differences in the organization of company-level activities. Systematic differences in the organization of careers, in patterns of company organization, and in relationships between firms and owners and investors exist across the two countries. Analysts have linked these differences in company organizational structures to the broad pattern of industry specialization and innovation patterns across Germany and the United States. I will now outline the German case in more detail, using somewhat stereotypical descriptions that, we will see when discussing the biotechnology case in more detail, have begun to evolve in recent years.

First, how are **careers** for scientists and managers organized? In Germany most employees spend most of their careers within one firm, often after a formal apprenticeship or, in the case of many engineers and scientists, an internship arranged in conjunction with their university degree. While there exist no formal laws stipulating lifetime employment, German labor has used its power on supervisory boards as well as its formal consultative rights under codetermination law over training, work-organization, and hiring, to demand unlimited employment contracts (Streeck, 1984). Once the lifetime employment norm for skilled workers was established, it spread to virtually all mid-level managers and technical employees. One result of life-time employment is that the active labor market for mid-career managers and scientists is limited (see Lehrer, 1997, Monks and Minow, 1995: 287-295).

Long-term employment and the „stakeholder“ model of corporate governance have important repercussions for patterns of **company organization** (Charkham, 1995; Lane, 1989; Vitols et al., 1997). Long-term employment and codetermination rights for employees create incentives for management to create a broad consensus across the firm when making major decisions. Because unilateral decision-making is limited, it is difficult for German firms to create strong performance incentives for individual managers. As a result, performance rewards tend to be targeted at groups rather than individuals within German firms. Until early 1998 stock options, one of the most common incentive instruments used in American firms, were illegal in Germany. Finally, most career structures are well defined in German firms and based on broad education and experience within the firm, rather than short-term performance.

Ownership and financial relationships in Germany are strongly influenced by corporate governance rules. Despite the recent expansion of equity markets, Germany remains a bank-centered financial system. Banks and other large financial actors (e.g. insurance companies) have a strong oversight role on firms through seats on the supervisory board and through continuing ownership or proxy-voting ties with most large German industrial enterprises (Edwards and Fischer, 1994; Vitols, 1995). Most German firms rely on banks or retained earnings to finance investments. Banks can often adopt a longer term focus in part because they know that German firms are able to offer sustained commitments to employees and other stakeholders to the firm, and can often closely monitor the status of their investments through seats on the supervisory board or other direct contacts.

Proponents of the varieties of capitalism perspective argue that German patterns of market coordination facilitate the creation of organizational competencies necessary for firms competing in sectors characterized by incremental innovation processes within established industries, such as many segments within the metal-working, engineering, and chemicals sectors (Streeck, 1992). Deep patterns of vocational training within firms, consensual decision-making, long-term employment, and patient finance are all linked to the systematic exploitation of particular technologies to a wide variety of niche markets, a strategy Sorge and Streeck label „diversified quality production“ or „DQP“ (Sorge and Streeck, 1988). On the other hand, scholars have suggested that the regulative nature of German economic institutions combined with pervasive non-market patterns of coordination within the economy create constraints against the organization of industries that best perform within shorter-term, market based patterns of coordination (Soskice, 1997). The American institutional environment, due to it’s more flexible but short-term oriented system of company organization and finance, is seen to facilitate more „radical“ or product based innovation strategies.

The general implication of the varieties of capitalism view is that national patterns of specialization will be enduring**.** Short of fundamental institutional change, policies designed to promote the creation of industries that are not favored by the country’s patterns of comparative institutional advantage will be unsuccessful. This leads to the conclusion that country-specific policies should be crafted to „fine-tune“ their particular institutionally derived location advantages, rather than attempt to craft policies to compete in industries requiring institutional supports at odds with the prevailing logic within the economy.

b) The resource orchestration perspective

While industry specialization patterns from the 1980s and early 90s broadly support the varieties of capitalism view (Cantwell and Harding, 1998; Casper et al., 1999), recent developments in Germany have been interpreted to strongly contradict it. During the later half of the 1990s Germany has witnessed the beginning of what many commentators, particularly within the business press, are proclaiming to be a renaissance in the performance of its high-technology industries (*Wirtschaftswoche*, 1998). In particular, a number of new technology policies are being credited with an expansion of entrepreneurial start-up firm activity. Biotechnology has been the sector with the most drastic reversal of fortune. Hampered by a hostile regulatory environment for genetic research throughout the 1980s and early 1990s in addition to institutional constraints, there were very few commercial biotechnology labs created in Germany, either by established large pharmaceutical firms or start-ups. However, starting with a liberalization of genetic testing regulations in 1993 and, beginning in 1995 with the introduction of substantial technology promotion programs for biotechnology, over five hundred new biotechnology start-up firms have been created in Germany in recent years, most centered around German university and public research institutes (Ernst and Young, 1998c. Similar expansions of commercial activity have taken place in other technology sectors, in particular software and telecommunications (Casper et. al., 1999).

During the mid-1990s a widespread discussion over its „innovation crisis“ raged within Germany. This debate has lead to the introduction of a substantially different analysis of the sources of commercial innovation within the economy, focusing less on national institutional determinants of innovation processes and more on the orchestration of resources and organizational competencies deemed necessary to innovate in particular sectors. The new sentiment is found in a recent report by the IFO-institute, a respected voice on German competitiveness issues: „If there is an ‘innovation crisis’ in Germany, then this ‘crisis’ is due…to a high degree of inertia in shifting capital investments, human resources, and existing ingenuity talents from traditional to new high-tech areas promising higher growth rates in the future.“ (Buechtemann and Ludwig, 1996:36; see also Audretsch 1985). The implication of the resource orchestration view is that the government should search for obstacles blocking innovation processes within particular sectors and introduce new policies to transfer resources and orchestrate the coordination of the necessary linkages within the innovation chain.

Following this logic, the German government has introduced a range of new technology policies designed to create clusters of entrepreneurial start-up firms, and in particular spin-offs from universities. University spin-offs have been one of the strongest sources of high-technology growth in the United States (Rosenberg and Nelson, 1994). German commentators have noted a number of obstacles to the creation of small entrepreneurial science-based firms with strong links to universities. In Germany the relationship between universities and the private sector is strong, but the primary technology link has been with large firms (Abramson et al.,1997). Under German law professors own most intellectual property and generally have long-term relationships with established firms. Universities have thus had little incentive to establish technology transfer labs. Rsearch within the bio-medical sciences and other „pure“ research fields has until recently been conducted with minimal attention to possible commercial spin-offs. As a result, the small-firm spin-off dynamic that has become commonplace within the United States has failed to develop within Germany.

Taking careful note of these and other „obstacles“ to the establishment of small entrepreneurial start-up firms, German public officials at the federal and state level have in recent years crafted a dense network of support policies. These initiatives, outlined within table 2, have explicitly attempted to orchestrate various linkages in the commercial innovation process, particularly focusing on university spin-offs. Biotechnology has been the most active area of governmental intervention. As part of a federally funded „BioRegio“ competition that began in 1995, 17 different German regions have created government biotechnology promotion offices. While regional experimentation has lead to some variation in the implementation of particular programs, technology offices generally aim to help scientists and local entrepreneurs organize virtually every phase of start-up formation within the biotechnology sector. This includes the hiring of consultants to persuade university professors or their students to commercialize their research findings and help them design viable business plans, subsidies to help defray the costs of patenting their intellectual property, and the provision of management consulting and partnering activities once new firms are founded. Most of the BioRegio programs have used public funds to create new technology parks and „incubator labs“ to house fledging start-ups in and around universities or public research labs.

The technology transfer offices created through the BioRegio programs are also the main coordinators for the disbursement of an array of grants, loans, and subsidy programs created in recent years for high-tech start-ups. In 1996 the German federal government, wary of criticisms of the lack of venture capital in Germany, decided to provide „public venture capital“ in the form of „sleeping“ or silent equity partnerships from federal sources (see Adelberger, 1999). The public agency created to oversee this program, the *tbg*, has provided on average over 200 million DM to new start-up firms over each of the last three years, with biotech firms being the largest recipient of seed-capital (some 22% of start-ups as of March 1999, according to officials working within the *tbg*). To increase their leverage and reduce the risk of opportunism, federal funds have generally been provided only when firms can obtain matching funds from „lead investors“ within the private economy. In addition, the German Research Ministry has provided over DM 150 million in grants for „pre-competitive“ research and development by start-up firms; money that has often been matched by groups of local large firms or government funds within individual BioRegions.

The German government has also worked with the financial community to introduce measures designed to stimulate the provision of higher risk investment capital and allow technology firms to undertake rapid growth trajectories commonly seen within American technology clusters. These reforms include the creation in 1997 of a new stock exchange, the *Neuer Markt*, with substantially less burdensome listing requirements than those that exist for the main stock market, and the introduction in March 1998 of a change in corporate law that allows firms to more easily buy and sell their own shares (a prerequisite for stock option plans commonly used by US technology firms).

These new technology policies have been enacted in an environment that has seen no major changes to the broader economy-wide institutional frameworks that proponents of the varieties of capitalism perspective stress to be so central. No reforms to German labor law, codetermination law, or company law appear to be on the horizon. Compared to the US or the UK Germany is still a primarily bank-centered financial system; at the end of 1996 German market capitalization was only

21% of GDP, compared to 151% in the United Kingdom and 121% in the United States (*deutsche Bundesbank*, 1997).

When the success of recent German technology policies is taken into account with the overall stability of German national institutional frameworks governing the economy, the resource orchestration perspective contains a markedly different view of the degree to which organizational structures within the economy are embedded within institutions. It suggests that sector-specific support structures can essentially circumvent the „normal" institutional incentives and constraints within the economy. If correct, this has important repercussions for the debate on the sources of organizational competitiveness and on public policy more generally. A „hybridization" of a country's institutional framework could occur (see Lane, 1999; Glimstedt, 1999). Firms with strategies that are advantaged by a country's „normal" institutional infrastructure could continue to engage those institutions when creating their organizational structures. Firms seeking to generate organizational structures in institutionally impoverished areas could do so through engaging specialized institutions created through sector specific technology policies. A plurality of institutional support systems, targeted at the unique needs of firms with particular organizational needs, might conceivably be created.

The recent expansion of German biotechnology and other high-tech industries demonstrates that a simplistic, static version of the varieties of capitalism approach is inadequate to explain instances of organizational change within the economy. Patterns of industrial organization have adapted within Germany to the innovative challenges posed by biotechnology and other new technologies, and technology policies have played a key role. A key question for research is to assess the degree to which these developments are discontinuous with general patterns of market regulation and industry coordination within the German economy. The varieties of capitalism and resource orchestration approaches both view institutional environments as critical determinants of organizational structure and, in effect, competitive performance. Micro-level research is required to assess how particular institutional frameworks are influencing the organizational characteristics of firms and other actors within commercial innovation networks. I now examine the biotechnology case more carefully.

3. Technology regimes and organizational dilemmas within biotechnology

When considering biotechnology, public attention has focused primarily on one segment of this industry, therapeutics. This is the area where spectacular advances have been made in the harnessing of molecular biology and genetic engineering techniques to understand the precise mechanisms underlying particular physiological processes and the discovery, or more often, design, of a variety of new treatments against disease. However, industry analysts have long noted that, even within bio-medical related biotechnology several important market segments exist. Table 3 defines the four most important market segments, using standard industry definitions and examples.

Particularly important in recent years has been the rise of numerous high-value added „platform technologies." Firms in this market segment attempt to create enabling technologies that are then sold to other research labs. Products include consumable kits used to rationalize or automate common molecular biology lab processes, such as the cloning of target strains of DNA for lab work (PCR) or the purification of DNA and other important molecules. Platform technology firms have also developed a number of information technology based applications that have been used to revolutionize many aspects of the discovery process within therapeutics. These include extremely high throughput „combinatorial chemistry" applications to aid the screening of potential therapeutic compounds and the development of genetic sequencing and modeling techniques to aid in the quest to fully decode and understand the human genome („genomics").

Important differences in patterns of sub-sector specialization exist between Germany and the United States. In addition to manufacturing and contract research activities which tend to be represented in all countries with large public or private medical research sectors, Germany's new biotechnology firms, with few exceptions, have overwhelmingly chosen to specialize in platform technology areas, while very few firms have become pure therapeutic research laboratories. For example, a recent survey of European biotechnology firms asked over 300 firms to identify all market sectors in which they conduct activities. While close to 40% of European biotech firms are developing therapeutic products, less than 20% of German firms are in this field. Conversely, about 30% of German firms are developing platform technologies, compared to less than 20% for the European industry as a whole (Ernst and Young, 1998b 19). When German biotech firms were asked to list the areas of their research activities, therapeutics came in fifth, ranked well below contract research and manufacturing, platform technologies, diagnostics, and „other services." (Ernst and Young, 1998b: 17).

More impressionistic field research yields a much stronger trend towards specialization in platform technologies than indicated in this survey data. As part of a research project on German biotechnology, I have attended roundtable presentations by leading German biotechnology firms at European and German industry conventions, conducted interviews at several of the leading German biotechnology firms, and also interviewed technology promotion officers in the four largest German biotechnology clusters. During this research I have failed to identify any German firms that conducts pure product based therapeutics research along typical applied biomedical research models often used by US drug discovery start-ups. Of the two German firms that have taken public stock listings and the four that are currently in the run-up stage, all are platform technology firms (*Wirtschaftswoche*, 1998). Most German „therapeutics“ firms are actually conduct contract genomics based research for pharmaceutical firms or therapeutics research firms. These firms may someday develop medical research competencies along the lines of leading US genomics firms, such as Incyte or Millenium Pharmaceuticals. However, so far only one prominent German genomics firm, the Genome Pharmaceutical Corporation near Munich, has developed internal medical research competencies, but only after this lab was financed by a large „pre-competitive“ research grant from the Bavarian government in late 1998.

As the location of the world’s overwhelmingly dominant biotechnology sector, many American firms have also specialized in platform technologies, but are also present in very large numbers in therapeutic areas. There are presently over 100 publicly traded biotechnology firms in the United States, most of which conduct active therapeutics research (see SG Cowen, 1999). This does not include dozens of privately held firms, not to mention the many hundreds of firms that have failed or have lost their autonomy through merger and acquisition activities (see Florida and Kenney, 1988; Senker, 1996).

An interesting empirical puzzle is thus why German firms have gravitated towards platform technologies while firms in the United States have tended to develop far more firms within the therapeutics area. One way to understand differences across the therapeutics and platform technology segments is to analyze several underlying technological and market characteristics of the two market segments. Differences in the underlying „technological regime“ underpinning these market segments can be used to identify a series of organizational dilemmas created for firms operating within each segment. While there are numerous competing technological regime classifications, here I draw on a typology developed by Breschi, Malerba, and Orsenigo in their efforts to examine sectoral systems of innovation (Breschi and Malerba, 1997; Malerba and Orsenigo, 1993). They examine four broad characteristics: opportunity condtions, levels of appropriability, technology trajectories within the industry (also known as „cumulativeness“), and the nature of technological knowledge. I will now examine each of these areas, paying particular attention to the degree of cumulativeness and the nature of knowledge, characteristics where important differences exist across the two sub-sectors.

<u>Opportunity conditions</u> correspond to the likelihood that particular investments will yield commercially relevant innovations, and are generally high for both therapeutics and platform technology firms. Intellectual property in therapeutics is very fragmented across literally hundreds of separate research trajectories. To place the extreme openness of the biotechnology field in perspective, consider that while scientists have uncovered tens of thousands of possible genetic targets within the human genome, the entire collection of drugs on the market today act through only 400 targets (SG Cowen, 1998: 23). Though patents for individual drugs (and gene

sequences) are strong, intellectual property across these separate research clusters has generally not overlapped in such a way as to „block“ on-going research within competing research clusters. For example, in an extensive mapping of research clusters working to develop therapies for Alzeihmer's Disease, Pennan (1996) identified some 15 distinct research programs racing against each other. To give an indication of the ease of entry, according to a recent industry analysis, some 90% of patented drugs have direct competitors, and there exist three or more direct competitors for 15 of the 20 top selling drugs (Powell, 1996: 204).

A similar situation exists within the platform technology field. The extremely large billion dollar plus research and development budgets of large pharmaceutical firms combined with the smaller budgets of thousands of biotech start-ups and non-profit medical research labs to create a vast market for products that simplify bio-medical research processes. Over time, the platform technology field might become more concentrated along a normal technological life-cycle logic as a smaller number of truly effective technological approaches develop and begin to be exploited by early innovators and consolidated into integrated „solutions“ that are sold to labs. However, because the segment has only developed into a major market niche in the last few years, it still is at the beginning of such a cycle, in which the opportunities for entry are extremely broad.

The <u>level of appropriability</u> relates to the ease with which the firm or networks of firms involved in the innovative activity can protect the innovation from imitation, and ranges from high to low (see Teece, 1986). Appriability conditions are often problematic for firms in both therapeutics and platform technology segments, though somewhat offset by the huge size of potential markets for products created by each type of firm. Biotechnology firms currently develop within a strongly constraining industrial environment imposed by the preexisting structure of the global pharmaceutical industry and university based bio-medical research (McKlevey, 1997). Within the pharmaceutical industry, only about 20% of total research and discovery expenditures are spent on the discovery of new therapeutic compounds – the major activity affected by therapeutic biotechnology firms. The remaining 80% of R&D is spent on the development of candidate compounds, including highly specialized activities such as several stages of preclinical and clinical trials and the submission of extremely complicated statistical studies that are necessary for regulatory approval. The market and distribution of new drugs – which according to one industry analysis is in itself as costly to pharmaceutical firms as research and develop (McGahan, 1994) – also remains primarily dominated by large pharmaceutical concerns. With the partial exception of Amgen and Genentech, two of the original biotechnology companies which have used high profits to transform themselves into small integrated pharmaceutical houses, virtually all new drugs discovered by biotechnology firms have been brought to market through alliances or direct sales of candidate compounds with established pharmaceutical companies. Therapeutic firms must manage risky, long-term alliances with pharmaceutical firms in a way that does not lead to a substantial transfer of rents generated by the firm's discoveries to integrated pharmaceutical firms.

Platform technology firms also face appropriability risks, but of a somewhat different nature. Intellectual property is not as strong as that within therapeutics, meaning that several firms usually enter technology areas with particularly lucrative returns. Within the lab technology area, services seen as exotic a few years ago, such as the cloning of target strains of DNA for lab work (PCR) or the purification of DNA and other important molecules, are now widely available. A similar phenomenon has occurred within the genomics field. Providing access to libraries of genetic sequence, a high-profile activity during the mid 1990s, has become only a few years later a readily available service. The high profile (and value added firms) today are moving into the „functional genomics" field, which attempts to embed particular genetic sequences with broad indicators of the biological activities with which these genes are likely to be associated. Competition within particular product markets allows pharmaceutical firms and other major customers to negotiate lower prices for services than those expected by the biotechnology firm, especially for larger contracts or high-volume purchases. To overcome the commodification problem, firms working within these areas must work to simplify such processes even further, often through integrating several such technologies into a sophisticated „platform" that can be sold or licensed to customers.

A third technological characteristic, the <u>degree of cumulativeness</u> or technological trajectory, relates to the volatility of technology within the firm's field of research. Technological trajectories vary on a scale from discrete to cumulative (see Breschi and Malerba, 1997: 135-136). Discrete technological trajectories have two components. First, the competencies needed to organize sequential research projects tend not to be stable; i.e. in a series of research projects that is necessary to bring a product to market, it is often difficult for a firm to foresee the particular competencies it will need to organize research project „B" before the results of project „A" are completed. This means that the firm must be able to quickly reconstitute its competency structure over the course of its research endeavors. Second, due to the radical or novel nature of many emerging technologies, a high percentage of research projects will fail to meet their goals. Cumulative research trajectories, in contrast, are not competency destroying. The risk of particular research projects failing is lower, and competencies tend to remain stable and predictable across the sequence of projects leading to the development of saleable products.

Technological trajectories within therapeutics tend to be extremely volatile or discrete. Firms often are constituted on the basis of theoretical expertise pertaining to particular therapeutic research areas, and then develop or acquire any number of particular application technologies needed to pursue projects as research progresses. Ethnographic accounts consistently document the widely changing course of therapeutic firm research activities over time as results develop, which often leads to repeated changes in the competency structure of the firm (see Werth, 1993). While technological uncertainty is a prime determinant of the high failure rate of particular projects, the high prestige and financial value generated by important research results leads to the development of „racing" activity across several firms (or networks of several firms) to develop technologies targeted at particular diseases. These races usually have several clear stages, e.g. the understanding of key mechanisms involved in disease; the discovery of key proteins or other molecules involved in disease processes; the discovery of possible routes of interdiction; the discovery of the molecular structure of key proteins/molecules or the discovery of genetic sequences of these molecules; the creation of candidate compounds; clinical testing, leading finally to regulatory approval.

Failure rates and time horizons, as seen in table 4, are high throughout the drug development process. No approval probability statistics exist for the discovery stage, as results here are wildly uncertain and varied across firms with particular research approaches. Firms using high throughput screening and other combinatorial chemistry techniques to automate traditional „chemical“ screening processes may only generate one „hit“ in tens of thousands of tests, but can run these tests very economically on a per test basis. Other firm using „rational drug design“ techniques might spend many moths if not years on the construction of particular drug candidates, but through doing so achieve a much higher percentage of candidates that can enter into pre-clinical testing.

Platform technology firms tend to develop more stable or cumulative technologies. Most firms begin with expertise in one or more process technologies that can be applied to a particular group of common molecular biology research activities. They then hope to expand into related areas on a sequential basis based on learning externalities generated through the completion of particular projects. For example, one of the first and the most successful German biotechnology firms, Qiagen, was founded in 1984 on the basis of the founder’s doctoral thesis on the creation of nucleic acid filtration devices. Over the last 15 years the firm has generated over 225 products that largely represent extensions of this initial technology. While competition is also fierce in the platform technology segment, the creation service-oriented end-user relationships leads to more market fragmentation across firms, muting the winner-take-all atmosphere generated within many research races within therapeutics.

A final technological characteristic concerns the type of technological knowledge that is generated through research and development projects, the knowledge property (see Winter, 1987). Once a particular research project is completed, a key question becomes whether research results and other assets developed within the project can easily be assessed by the firm’s management and other outsiders to the particular project. If research results can be codified, then financiers and management can more easily monitor the activities of scientists and technicians within the firm. If research results remain tacit, then it becomes difficult for management and outsiders of the firm to assess the value of research results over the short to medium term, until final products can be completed and sold. Furthermore, work groups hold high amounts of „know-how“ that cannot be easily transferred to other employees or used as easily assessed intellectual property that can leveraged for financial investments.

Most knowledge within therapeutics research quickly becomes codified and assessable to participants across a research field. At the end of each „race“ or research stage the winners develop codified intellectual property which, we will see, is often leveraged for additional research funding or sold on the market. Losers usually receive the results of each stage in terms of codified knowledge (conference presentations, journal articles or patent applications) and can decide if they want to enter the next stage. In addition to scientific publications and patent documents, a number of industry analysts publish newsletters and quarterly „scorecards“ tracking the progress of particular firms.

Platform technology firms often generate considerable long-term tacit knowledge within research groups. This is strongly influenced by the more cumulative nature of technological advance within most platform technology firms. While most therapeutics firms organize R&D along clear research goals, platform technology firms often generate revenues through serial projects that involve the application of the firm’s core technologies to help solve particular problems of customers. Over time, the scientists and technicians involved in these projects make incremental improvements to technologies and add new competencies, most of which feed back into the firm’s core technological know-how. Incremental learning processes conduce towards the accumulation of tacit knowledge within particular teams of scientists and technicians. Appropriability concerns also create a motive to avoid codification of important technical knowledge. When intellectual property is weak, firms have an incentive to create trade secrets that cannot be easily gleaned by outsiders. While the German firm Qiagen, for example, has patented many of its filtration technologies, the long-term applied nature of much of its research has created considerable tacit knowledge within the firm’s R&D department that which the firm sees as a barrier to entry, especially when its key patents begin to expire in the next several years.

Using these technological characteristics, it is possible to identify three major classes of persistent organizational risks that the actors involved must resolve if organizational structures to innovate within the segment are to be reliably created and sustained. These risks include: a) problems created by the destruction of competencies within the firm as research progresses, b) financial difficulties, and c) dilemmas concerning employee motivation.

Competency destruction risks. This risk is primarily determined by the technological trajectory, and is much higher in therapeutics than most platform technologies. Most biotech start-ups involved in therapeutics research eventually fail and either enter into bankruptcy or are sold to other firms (see Senker, 1996; Powell, 1996). Therapeutics research, even within successful firms, is often characterized by patterns of internal competency destruction. As a result, the career risk of working within any given biotech firm must be low. Furthermore, as Powell (1996), Pennan (1997) and others have discussed, therapeutics based research is a network based industry. Innovation is dependent on the flow of knowledge between university labs, start-up research firms, and large pharmaceutical firms. While joint research projects, strategic alliances and so forth facilitate this exchange of knowledge, these network externalities are also supported by the rapid movement of scientists and technicians across firms.

When competency destruction is high, asset recycling becomes an important organizational problem (Bahrami and Evans, 1995). Therapeutics firms must be able to quickly reconstitute their competency structures over the course of its research endeavors. They must have access to a pool of scientists, technicians, and other specialists with known reputations in highly specialized areas that can quickly be recruited to work on research projects. Because many projects will fail, coordination mechanisms to „recycle“ sophisticated assets across the matrix of public and private research clusters must be developed. If asset recycling is difficult, then specialists may choose not to commit to firms with high-risk research projects, for fear that if the project fails the value of his or her research assets could significantly decline. Similarly, if extensive lateral career mobility across firms and non-profit research labs is not supported, then network externalities driving innovative research clusters would be difficult to sustain.

Financial risks. While therapeutics and platform technology firms both require significant ongoing capital investments, they tend to generate different financial risks. Frequent failures and very high investment rates generated by the nature of technological volatility and short-term competition across research races create substantial financial risks for therapeutics firms. While reliable financing figures for each stage are not readily available, most industry guides estimate that the total cost of discovering and developing a new drug is between $100 and $200 million (PhRMA,1997). These costs increase dramatically as products are discovered and developed; while the research required for drug discovery typically can be financed through a few million dollars per year, the cost curve dramatically escalates once potential target compounds are discovered and clinical trials involving human participants begin. The 7-10 year time horizon between discovery and a new drug reaches the market compounds these risks

These extreme financial risks may be offset somewhat if firms codify key scientific results into intellectual property that is strongly protected through patents. Results generated through all aspects of therapeutics research may, if the firm chooses to codify and release the information, be widely reported and monitored throughout the research community. This allows investors the possibility of developing mechanisms to monitor each firm and gradually extend financing as warranted through positive results. Furthermore, while the odds of successfully bringing a product to market are low, the payoffs can be astronomical. Consumers have repeatedly been willing to support very high prices for effective new treatments, creating billion dollar plus returns for some drugs. Risks can also be pooled through forming joint ventures, in particular with large pharmaceutical firms, which have dedicated in-house development expertise, particularly in latter stage clinical trials, negotiating the FDA approval process, and in marketing and distribution.

While platform technologies vary in the financial risks involved, they are generally lower than for therapeutics firms. The technology commodification problem caused by relatively low long-term levels of appropriability tends to weaken the earnings potential of innovations and creates pressure for firms to continually improve existing products or introduce new ones. Initial capital costs are often higher, especially for firms that require access to sophisticated lab equipment (e.g. gene sequencing devices or dedicated machinery for the production of products). However, many platform technology firms avoid this problem by beginning with relatively modest amounts of seed capital, which is used to rent time on sophisticated lab equipment owned by the basic research laboratories from which the new enterprise is spun out. They can then attempt to arrange larger amounts of finance once the new firm has reached a critical mass of customers and services to justify the construction of sophisticated capital assets in-house. Moreover, because most platform technology companies aim to sell services or products to other labs, time horizons are much shorter before the firm begins to generate income flows, and there are usually no significant regulatory approval costs and subsequent delays. An additional tactic is to embark on so-called „hybrid“ strategies, focusing on a mix of short-term service oriented projects to generate cash flow, but also some medium to long-range products aimed at larger technology markets with potentially larger returns. For example, many genomics firms start by selling access to genetic libraries and related sequencing services to labs engaged in therapeutic research, but hope to eventually develop the financial backing and in-house competencies to pursue their own therapeutic projects.

Employee motivation risks: Once a firm has obtained the necessary human and financial resources, it still must create organizational structures necessary to innovate. Because most biotechnology firms are small, developing adequate formal organizational rule systems is usually only a minor problem; semi-autonomous and largely self-governing research groups are the norm within virtually all biotechnology firms in both segments. The key risk factor rather involves creating adequate incentives for employees to commit to what are often demanding, extremely competitive and time-intensive work environments that exist within both therapeutics and platform technology firms. Employee motivation problems are perhaps the major reason why most biotechnology firms are small (rarely more than 50-100 people, including administrative staff, and usually much smaller than this during formative years). Small numbers facilitates mutual monitoring and may, if the managers choose, be used to create ownership or remuneration structures that give each employee a large stake within the success of the firm. In addition to this general commitment problem, employee motivation difficulties may be also created by „hold-up“ risks created by the extreme specialization of knowledge within biotech firms and, in some cases, problems created when employees are asked to invest in firm-specific skills that have a limited value outside the firm (see Miller, 1992).

Employee motivation can be particularly challenging for platform technology firms. While management must create a high-powered work environment to successfully compete, the existing of long-term tacit knowledge means that managers or other outsiders cannot easily monitor the activities of particular work groups or develop simple contractual structures rewarding employees for short-term achievements. Long-term relational contracts must be developed between researchers and the management and owners of firms in order to create incentives for research groups to accurately report their results. When employees spend long amounts of time with the firm, there is the risk that the cumulative nature of technological progress may generate substantial firm-specific know-how. If the firm should collapse the value of the employees skills might be discounted on the open labor market. Knowing this, the firm's management, once the employee made investments in firm-specific skills, could credibly demand that the employee accept remuneration at this discounted rate. While doing so seems unlikely given the overarching desire from management to create high-powered incentives for employees to work in work-intensive environments, should the firm encounter financial difficulties, employees with substantial firm-specific skills could be at a disadvantage compared to employees that have only invested in general skills that are readily saleable to other firms.

Employee motivation problems within therapeutics firms are somewhat mitigated by the ability to codify most research results. The chief employee motivation problem within therapeutic firms is creating high-powered work environments necessary to succeed in extremely competitive research races. Management also face a concern that scientists may attempt to „hold up“ the firm through refusing to codify the knowledge until particular demands are met. This typically leads to the creation of very high-powered incentives for particular researchers. Researchers may be given formal incentive contracts developed by managers whose value depends on the generation of particular codified research results. Another common tactic is to allow scientists to share the limelight generated by important discoveries through encouraging scientists to publish important results in high-profile scientific journals. Overall, the ability to codify most research results means that long-term tacit knowledge problems are less frequent, while the turbulent nature of technological change and subsequent high recycling of employee assets across the community of firms lowers the firm-specific knowledge risk.

Table 5 summarizes this general discussion.

4. The institutional determinants of organizational governance within the US and German biotechnology industries.

We have now examined organizational dilemmas underlying innovative activity within the therapeutics and platform technology segments of the biotechnology industry. Though „internal“ technological and market contingencies may present some obvious governance mechanisms the actors involved may choose to develop (such as, for example, the ability of therapeutics firms to use codified knowledge as a device to structure employee performance incentives), the core institutional argument is that firms must chiefly draw upon resources external to the firm if they are to successfully resolve their organizational dilemmas. In this respect, institutions may be regarded as „tool kits“ (Swidler, 1986) actors may draw upon to create governance mechanisms needed to structure their social interactions.

In general, the resource orchestration view focuses on the role of policy in creating the substantive forms of coordination needed to compete within particular sectors. Which actors must be present, what broad organizational forms should they adopt, and what resources do they need? In both the US and German biotechnology cases particular policies have had a determining influence on the development of commercial biotechnology. We have already noted the importance of German policies in stimulating the formation of new commercial biotechnology clusters. In the United States commentators have long noted the importance of extremely large federal grants dispersed by the National Institute of Health in fostering the US lead in bio-medical science (Kenney, 1986). Furthermore, a key technology policy developed in the late 1970s, the Bayl-Dole Act, transferred ownership of all intellectual property funded through federal research grants to universities, creating the stimulus needed for most universities to organize technology transfer offices (Abramson et al., 1997).

However, there is also a second, „relational“ level of analysis: Do sustainable incentive structures for all participants within the entrepreneurial firm and its immediate network exist? The organizational dilemmas commonly found within therapeutics and platform technology firms are primarily of this relational variety. While technology policies can sometimes help reduce some organizational risks, particularly with regards to finance, I will argue that economy-wide national institutional frameworks are the primary resources firms draw upon when creating the competencies needed to resolve each of the three core organizational dilemmas within commercial biotechnology. German and US national institutional frameworks tend to advantage different types of organizational solutions to the organizational dilemmas discussed in relation to biotechnology. This will help explain why German firms have tended to gravitate so strongly towards the platform technology segment while American firms, though strong in both areas, tend to be particularly dominant in therapeutics. I first discuss the orchestration of innovative competencies for therapeutics within the United States and then turn to the German case.

While the commercial innovation networks that have evolved in the United States are broadly consistent with the technological market characteristics embedded within the therapeutics sector, it would be misleading to suggest that the system evolved towards its current form based on efficiency or other considerations. Starting with Genentech, the original biotech start-up formed in 1976, biotechnology firms quickly became enmeshed within a network of largely market based relationships invented previously to support the semiconductor and computer industries (see Kenney, 1986). As a result, models of financing, firm-organization, and corporate governance for start-ups were largely imposed onto the new industry, rather than being developed for the industry. Because institutional frameworks governing most substantive areas within the United States are broadly enabling in nature and tend to support market forms of business coordination, it is not surprising that such mechanisms were chosen. The US therapeutics sector has thrived largely because market based governance mechanisms can be easily adopted to resolve the major organizational dilemmas underpinning these activities. This claim is supported through briefly considering each of the three organizational problem areas discussed earlier:

Competency destruction. In the United States the deregulated nature of most labor law has resulted in the creation of an extremely active labor market. Particularly in California (but generally throughout the US), courts have refused to enforce „competition clauses“ inserted into employment contracts to prevent poaching. While firms can ask employees to sign non-disclosure agreements covering specific technologies, scientists and managers are generally free to move from firm to firm as they see fit, while managers can shed assets through hiring and firing as circumstances within the firm develop. This has facilitated the creation of extensive head-hunting operations within most US technology clusters and, within firms, the organization of career paths within firms based on the probability of frequent employee turnover. Active labor markets facilitate rapid asset recycling to compensate for competency destruction created by the high rate of firm failure. (see Saxenian, 1996 for a general discussion of career-paths in Silicon Valley).

Financial Risks. Virtually all American therapeutic firms are initially funded by venture capitalists (see Florida and Kenney, 1986). Venture capitalists are usually willing to accept high technological uncertainty and short to medium term financial losses in return for the prospect of very large gains in the future. However, they also require the ability to segment the R&D activities of start-ups into several milestones with codified research results (high-prestige scientific publications and patents) that can be used to make further investment decisions and eventually become leverage to take the firm public. The codified nature of most scientific results in the therapeutics field easily fit into venture capital models of corporate finance.

There are important institutional reasons why the venture capital market is so large in the US. First, very substantial private legal competencies exist and, due to the „enabling“ nature of ownership and contract law, can be used to create sophisticated legal structures used to support risky new ventures (see Easterbrook and Fishel, 1991). These include the high-powered performance incentives for managers and scientists discussed above. Second, and probably most important, in the United States the property rights structure of firms is primarily financial in structure, and rooted in large capital markets (e.g. NASDAQ, NYSE). A liquid market for corporate control is critical for venture capitalists, as it creates a viable „exit option" via initial public offerings and mergers or acquisitions by other biomedical companies. Without this exit option, it is difficult for venture capitalists to diversify risks across several investments or create a viable refinancing mechanism. Successful start-ups will be given supplementary „mezzanine" financing and eventually taken public through an initial public offering (IPO) or sold to a larger pharmaceutical company, usually creating a very high return for the venture capitalists. These profits may be used to offset the losses on other companies and thus make a portfolio strategy more viable. Finally, by taking a firm public within a few years, venture capitalists create a viable refinancing mechanism. They can use the profits from IPOs to seed new ventures as well as provide secondary funding for other start-ups (for example, to take promising candidate compounds into clinical testing).

Employee motivation. Short-term performance milestones generated by the general pattern of competition within therapeutics and demanded by venture capitalists complements the creation of high-powered performance incentives for employees. Most companies motivate employees primarily with share-options, coupled with the announced intention of owners and venture capitalist to take the firm public within a few years. In the cases of successful firms that have gone public, share options can be worth from tens of thousands of dollars to junior staff to millions to senior scientists and owner/managers. The prospect of large financial rewards helps align the private incentives of scientists with those of companies and is a prime reason why US high-tech firms have become associated with extremely long work-weeks and general dedication to projects. Most technology companies also have annual performance reviews that are largely based on individual performance. Within therapeutics firms, this is usually pegged to each scientist's contribution to codified intellectual property developed within the firm. To aid the longer-term reputation should they reenter the labor market, scientists are also regularly allowed to publish key results in scientific journals under their name along with the firm's.

To fully appreciate the short-term, contingent nature of these relationships, a more systematic view should be taken. Each link of the competency chain must be credible before all actors will commit to working within a particular entrepreneurial project. For example, as Zucker and Darby (1997) have shown, successful biotech firms, particularly in their formative stages, are usually associated with „star-scientists" from universities that contribute seed technology, provide informal consulting, and serve on the firm's scientific advisory board. Fledging firms with high-profile scientific backing are the most likely to gain the attention of venture capitalists with access to generous financing, management know-how, and, of often critical importance to newer firms, the reputation needed to persuade high quality managers and scientists to work with the firm. Having this combination of assets will enhance the probability of the firm succeeding in early research races, and through doing so gaining access to further venture capital, and eventually access to the investment banking community as well as joint ventures with large pharmaceutical firms.

While such virtuous circles are common with therapeutic start-ups, they can quickly become vicious. If the firm cannot recruit high quality researchers or cannot attract start-scientists on its scientific advisory board, then it is unlikely that venture capitalists will support the firm. Similarly, when firms fail to meet important milestones the short-term and market driven nature of their organization facilitates their quick unraveling. Once a firm faces difficulties, venture capitalists will often decline to extend further financing, often forcing firms to sell valuable intellectual property at fire-sale prices to other biotech firms or pharmaceutical companies to stay alive. This could quickly lead to further difficulties as key researchers within the firm jump to other enterprises and star scientists affiliated with the firm turn their attention elsewhere. Such is the essence of a short-term, incentive based contracting scheme.

If, for institutional or other reasons, one or more links within the competency chain of an emerging therapeutics research enterprise is not credible, then it is unlikely that other participants will commit to a particular project. This is the key factor explaining why German firms have not gravitated towards the therapeutics area. Up until as recently as the mid-1990s, institutional obstacles created major hurdles to the creation of viable governance mechanisms in each of the three areas discussed. While minor institutional reforms and sector-specific technology policies have lessened some restraints, key problems, particularly in the area of arranging human resource competencies within quickly changing technology areas, continue to undermine the viability of most therapeutics projects in Germany. Having explained the market-based construction of American biotechnology firms, we can now better interpret developments within Germany.

The one area where economy-wide institutional reforms have benefited entrepreneurial firms is finance. While large German firms continue to be governed through a stake-holder model of company law, the management of many large companies have in recent years developed an interest in tapping international financial markets and broadening their shareholder base in order to generate shareholder value pressures, stock-option schemes and other mechanisms to increase short-term performance pressures within the firm. This has lead to an upsurge of investment banking activities and finance in Germany throughout the 1990s and facilitated in 1997 the creation of a NASDAQ-modeled stock exchange for technology companies, the *Neuer Markt*. While only one biotechnology firm, a genomics company, has had a successful IPO on the Neuer Markt, this market has successfully supported several dozen equity listings of German firms in other technology sectors, as well as a secondary listing for the German platform technology Qiagen.

Venture capital has until very recently been underdeveloped in Germany because of a lack of institutional mechanisms to support the rapid growth of firms through IPOs and other equity market activities as well as a credible „exit option“ for venture capital syndicates. Spurred also by large government matching grants for new technology firms, the development of capital market institutions to support equity based growth strategies has lead to the inflow of venture capital firms. While only two venture capital firms existed within Germany at the beginning of the 1990s, over 15 companies had set up shop in Germany by early 1999 (Mietzsch, 1999). Due to the liberalization of German share-holding law in March 1998, most German biotech start-up firms offer stock-options in order to foster intense work environments and are intent on leverage the firm's equity for further financing along American-style high-technology growth trajectories. While high capital gains taxes on stock options somewhat diminish their strength, German high-technology companies can now successfully mimic American-style employee motivation schemes.

Why, then, have the vast majority of the hundreds of new German biotechnology firms that have been set up largely in response to these institutional reforms and accompanying technology policies not adopted therapeutics strategies? The primary reason is that company and labor law continue to advantage the construction of organizational structures that are dramatically at odds with those that have traditionally been best suited for therapeutic firms. In addition, the structure of the German venture capital might be pushing firms into lower-risk market segments.

German technology firms face difficulties in obtaining the necessary human resource competencies to innovate in volatile fields with frequent technological change. Labor market institutions pose obstacles to the creation of coordination mechanisms needed to compensate for a high rate competency destruction and firm failure. Large labor markets for experienced scientists and managers simply do not exist in Germany. Both sides of the „hire and fire“ equation needed to support short-term incentive contracting are muted. While large German firms can sell entire subsidiaries or business units or send some lower-productivity older employees into early retirement, codetermination law makes it difficult for firms to lay-off individual employees or groups of employees as part of the „normal“ course of business. Because labor markets for mid-career managerial and scientific expertise are relatively underdeveloped in Germany, the asset recycling mechanisms needed for therapeutics firms to successfully compete in technology races over the medium to long term do not exist. As a result, the risk of „jumping ship“ from an established large company or prestigious university professorship to a start-up firm is extremely high. The lack of experienced managers and scientists willing to work within entrepreneurial start-ups is widely seen as the key constraint on the further enlargement of the German biotechnology industry (*Economist,* 1998).

The continuing development of German biotechnology is unlikely to lessen the asset recycling problem. Unless employees throughout the German bio-medical commercial and scientific research community begin to accept short-term incentive contracting arrangements, the extremely flexible labor markets to support therapeutics strategies seem unlikely to develop. While pharmaceutical firms in Germany have undergone recent waves of downsizing their corporate staffs, they remain strongly embedded within German company and codetermination laws that encourage large firms to offer long-term employment and related company organizational strategies (see Becker et. al., 1999 for a discussion of Hoechst's difficulties in this area). Though it is too early to confirm empirically, most platform technology firms in Germany are likely to develop long-term employment patterns too in order to develop relational contracting structures with employees. If most German biotechnology firms become relatively stable with low failure rates, then it is unlikely that they will eventually provide access to new pools of expert labor to work within therapeutics firms, since employment patterns will likely become predominately long-term. This could limit job mobility across these firms, especially if many employees over the years invest in firm specific skills. Turning to universities, while large numbers of German university professors have developed consulting relationships with Germany's new biotechnology firms, as of late 1998 no professor has been enticed to leave his or her university chair to work full-time within a firm. The primary source of employees (and entrepreneurs) for Germany's new biotechnology firms have been PhD students and postdocs from German bio-medical university labs who currently face extremely dim employment prospects within German universities.

While financing for entrepreneurial firms now exists within Germany, the governance of these investments is problematic. In addition to „silent" venture capital guaranteed by the federal government, much venture capital in Germany has been organized through „innovation funds" administered by the banking sector, and in particular the public savings and investment banks (see survey in Mietsch, 1999: 241-255). As pointed out by Tylecote and Conesa (1999), banks in „insider" dominated corporate governance systems tend to have excellent knowledge of particular firms, but usually do not have the detailed *industry* knowledge that is necessary for investors to channel money into higher-risk technologies. Rather, financing for successful higher-risk activities is generally provided by specialized venture capitalist houses, often in conjunction with industry „angels" that have detailed technical and market expertise within particular industries. The growth of German venture capital has been spurred by financial subsidies for start-ups. While there do exist several credible venture capital houses in Germany, the extensive involvement of public funds in syndicates backing most firms creates limits on the reservoir of experience the firm can draw upon through its venture capital partners. Furthermore, public officials involved in the administration of federal subsidies as well as officials of public banks, when interviewed as part of field research conducted in early 1999, consistently stated that „sustainability" was their core concern. Above all else, public officials want to avoid large numbers of corporate failures. In addition to risking moderate sums of public money, the political backlash created by a large number of high-tech failures could be embarrassing. Lacking the industry expertise to take an active role in the governance of these firms, it is not surprising that so many projects have been steered into lower risk market segments.

Finally, German financial markets for high-tech firms, while growing, are still embryonic compared to those in the United States or even the United Kingdom. The lack of a viable „exit option“ has limited the development of dedicated venture capital financing, and especially so-called mezzanine financing to fund the expansion of start-up firms in preparation for going public. While the early success of the *Neuer Markt* has been a positive development, the ability of investors to successfully adopt a portfolio approach when investing in extremely high-risk start-ups is far from proven. During 1998 the value of the UK biotech index, which is heavily populated by therapeutics firms, declined by half due to several unexpected failures, including a late stage clinical trial setback by British Biotech, the UK's leading biotech firm (see SG Cowen, 1998). Few German observers believe the *Neuer Markt* could easily absorb similar volatility. Until the market has successfully funded the development of several biotechnology firms, which will likely emerge from pure platform technology segments or, at most, from genomics firms venturing into limited therapeutics research, it is unlikely that investors will be likely to support large numbers of therapeutics firms in Germany.

It is this mix of entrepreneurial pressures and growth opportunities combined with „normal“ patterns of primarily long-term and relationally based company organization that characterizes most of the new German high-tech enterprises. Seen in this light, it is clearer why so many of Germany's new biotechnology firms have headed into the platform technology field. Most platform technology firms must be embedded within financial and corporate governance institutions that can support entrepreneurial growth strategies, but due to the complexity of the employee motivational problems, require the formation of longer-term relational contracts with employees to encourage them to invest in firm specific knowledge and reveal tacit knowledge to management. Furthermore, the cumulative pattern of technology development helps reduce the employment risk of joining a platform technology start-up. Government technology policies are ideally suited to these firms, since they provide incentives for universities to spin-off technologies and provide seed capital grants to incubate fledging new enterprises. Once firms begin to establish themselves on the market, venture capitalists can and have provided access to resources needed to fuel growth. Because German institutional frameworks strongly support the investment in firm-specific and long-term tacit knowledge within firms, it is not surprising that so many German firms have selected this area. Because they are embedded within a superior institutional environment, German firms could eventually outperform American firms in platform technologies.

5. Conclusion

Institutional change has clearly occurred within Germany. However, analysis of the activities of Germany's new firms supports a view of „accommodation“ or incremental adaptation of German institutional frameworks to support an expansion of entrepreneurial technological firms within the economy, but not a fundamental shift towards a „hybrid“ model as implied by the resource orchestration view. Germany's new technology policies have facilitated important extensions within the business system that have, for the first time, allowed the systematic promotion of entrepreneurial technology companies. However, the dominant strategies of market specialization and company organizational patterns found within these companies have been strongly influenced by incentives and constraints created by long-established national institutional structures. Most generally, German institutions tend to advantage innovation patterns in which knowledge cannot easily be codified and for which research trajectories are cumulative and have high degrees of firm-specific knowledge. Institutional frameworks within the United States advantage the construction of commercial innovative activities for which there is a large amount of competency destruction due to the discrete nature of technology trajectories but knowledge can be codified.

While the discussion has focused on biotechnology, firms in other German technology sectors exhibit similar characteristics. For example, a recent study of the emerging German software industry revealed that very few German firms have mimicked common strategies employed by US firms targeted at designing products for extremely large, „blockbuster“ markets. Rather, most German firms, following the lead established by the German software giant SAP, have targeted a wide variety of niche markets within the enterprise software business. This segment of the software industry has a technological and market profile almost identical to that in biotechnology platform technologies (see Casper et al., 1999).

The implications of this analysis for public policy are unfortunately not clear-cut. A key concept underlying the varieties of capitalism approach is that of *comparative institutional advantage* (Soskice, 1997). According to this concept, differences in institutional architectures across the advanced industrial economies advantage the creation of different company organizational structures necessarily to perform well in some groups of industries, but create constraints hindering performance in others. While the biotechnology case certainly supports this view, it carries the strong implication that little or no change is possible, or even necessary. However, German technology policies have successfully stretched the fabric of the prevailing institutional frameworks into new directions. The forging of new technology transfer links through the BioRegio programs combined with financial subsidies and reforms to promote the creation of high-technology corporate governance have combined to create extensions of the German model. However, we have also seen that this extension is strongly path dependent on prevailing forms of organization within the German economy, and in no sense can be described as a „break“ with the long-established „DQP“ model of company organization. While changes to the German technology transfer system have been clearly helpful, it is quite possible that many of Germany’s new platform technology firms may have emerged without extensive public financial subsidies. Technology promotion is possible, but policies should be crafted in ways that are broadly consistent with the country’s prevailing comparative institutional advantage.

An important theme for institutional research is to establish theoretically useful analysis that can more easily incorporate changes such as those presently occurring in Germany into normal categories of analysis. A middle ground, so to say, must be established between extremely rigid institutional theorizing implying that little change is likely, and analysis suggestion that extreme discontinuity is possible. Static descriptions of existing institutional environments must be combined with micro-level accounts tracing how firms, governments, and other actors within the economy engage and at times reconfigure the institutional tool-kits at their disposal.

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Table 1: National institutional frameworks in Germany and the United States

	Germany	United States
Labor law	Regulative (coordinated system of wage bargaining; bias towards long-term employee careers in companies)	Liberal (decentralized wage bargaining; few barriers to employee turnover)
Company law	Stakeholder system (two tier board system plus codetermination rights for employees)	Shareholder system (Minimal legal constraints on company organization)
Financial system	Primarily bank-based with close links to stakeholder system of corporate governance; no hostile market for corporate control.	Primarily capital-market system, closely linked to market for corporate control and financial ownership and control of firms.

Table 2: Recent German technology policies

Issue-area	„Obstacle“	Policy
Technology transfer	Universities in Germany do not own intellectual property have thus have little incentive or resources to organize technology transfer offices.	Create government sponsored technology transfer offices, technology parks, and services nearby universities.
Intellectual property	Professors own most IP generated within university labs but lack resources to commercialize IP.	Introduce government subsidies and hire consultants to help professors pay patenting costs and commercialize technologies.
Start-up firms	Fledging start-ups in Germany lack access to high-risk venture capital and low-cost support infrastructure.	Introduce subsidies for „pre-competitive“ research, and „public venture capital“ in the form of „silent partnerships“ for start-ups; build technology parks and „incubator labs“ to provide sophisticated infrastructure for start-ups at subsidized cost.
Start-up firm development and expansion	German financial laws have prohibited the use of equity-based stock-option schemes while structure of capital markets makes it difficult for high-risk technology firms to raise funds through public offerings.	Finance reforms allow firms to buy and sell own shares and introduction of a new stock market with lower listing requirements for technology firms.

Table 3: Bio-medical related market segments

Category	Definition	Examples
Therapeutics	Develop products to improve the treatment of disease	Apply a variety of molecular biology methodologies to discover/design drugs
Diagnostics	Develop tools to help identify diseases	Develop antibodies for use in diagnostic procedures; Some use of genetic technologies (e.g. PCR) to test for genetic diseases
Platform Technologies	Create enabling technologies with broad application	Genetic sequencing or engineering services; the creation of consumables for use in molecular biology lab procedures; combinatorial chemistry and other automation technologies
Contract Research / Manufacturing	Perform customized biochemical related services for other companies	The manufacturing of customized biochemical products; specialized services such as equipment servicing or quality control certification

Source: Industry definitions from Ernst and Young 1998a: 5-6.

Table 4: Time horizon and approval rates for therapeutic drug development

Drug development stage	Time horizon	Probability of approval
Discovery	2-3 years	
Pre-clinical	1 year	5%*
Clinical stage 1	½ - 1 year	23%
Clinical stage 2	1-2 years	31%
Clinical stage 3	1-2 years	64%
FDA Approval	½ - 1 year	75%

Source: SG Cowen 1998, pg. 22, 33;*this figure from BIA, 1999: 19.

Table 5: Organizational dilemmas within biotechnology market segments

	Therapeutics	Platform technologies
Competency destruction risks	**High** – Due to discrete nature of technology; asset recycling a key problem	**Lower** – Due to cumulative nature of technology and lower failure rate
Financial risks	**High** – Due to failure rate, long time horizons, and high „burn rate“; however codified knowledge facilitates short-term monitoring	**Low to Medium** – Failure risk lower and time horizons shorter, but tacit knowledge makes monitoring difficult and many product segments have become extremely competitive
Employee motivation risks	**Medium** – Firms face potential „hold up“ problem and must create high-powered incentives due to racing nature of research. But once scientists codify results performance may be easily monitored.	**High** - Long-term tacit knowledge makes monitoring difficult and cumulative research trajectories may create firm-specific knowledge risks for employees

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